

The background of the slide is a deep space image featuring a dark, star-filled sky. In the upper left, there is a bright, glowing spiral galaxy. To its right, a colorful nebula with shades of orange, yellow, and blue is visible. The bottom of the image shows a faint, horizontal band of light, possibly a distant galaxy or a nebula. The overall tone is dark and mysterious, typical of astronomical photography.

# **Technology Assessment Requirements for Programs and Projects**

Presented By  
**James W. Bilbro**

**Multi-Dimensional Assessment of Technology Maturity  
Workshop  
9-11 May, 2006**

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# Technology Assessment Requirements for Programs & Projects

## What is Technology?

"1.a. The application of science, especially to industrial or commercial objectives\*. b. The entire body of methods and materials used to achieve such objectives."

- The American Heritage Dictionary

\*or in NASA's case space

# Technology Assessment Requirements for Programs & Projects

## What is Technology Assessment?

- It is a continuous, iterative process that must begin at the earliest stage of a pre-program (i.e. concept development - Pre-Phase A) and continues throughout the life of the program until final design and development begins (i.e. Phase C/D.)
- It in fact provides critical products for key decision points (KDPs), (or gates) that allow transition between program/project phases.

# Technology Assessment Requirements for Programs & Projects

## What is Technology Assessment?

- It is a two-step process that involves:
  1. The accurate determination of the Technology Readiness Levels (TRLs) (i.e. current level of maturity).
  2. The accurate determination of the Advancement Degree of Difficulty (AD<sup>2</sup>) (i.e., what is required to advance a technology from its current TRL to what is required for infusion into the program/project at an acceptable level of risk.)

# Technology Assessment Requirements for Programs & Projects

## What is a Technology Readiness Level (TRL)?

- At its most basic, the TRL is a description of the maturity of a given technology defined by what has been done, under what conditions at a given point in time.
- However, the TRL is just one part of the equation – it establishes the baseline.
- The more fundamental question is what is required (in terms of cost, schedule and risk to move the technology from where it is to where it needs to be.
- In addition, there is an organizational aspect of technology assessment that speaks to the capability of a given organization to reproduce a technology irrespective of its maturity level.

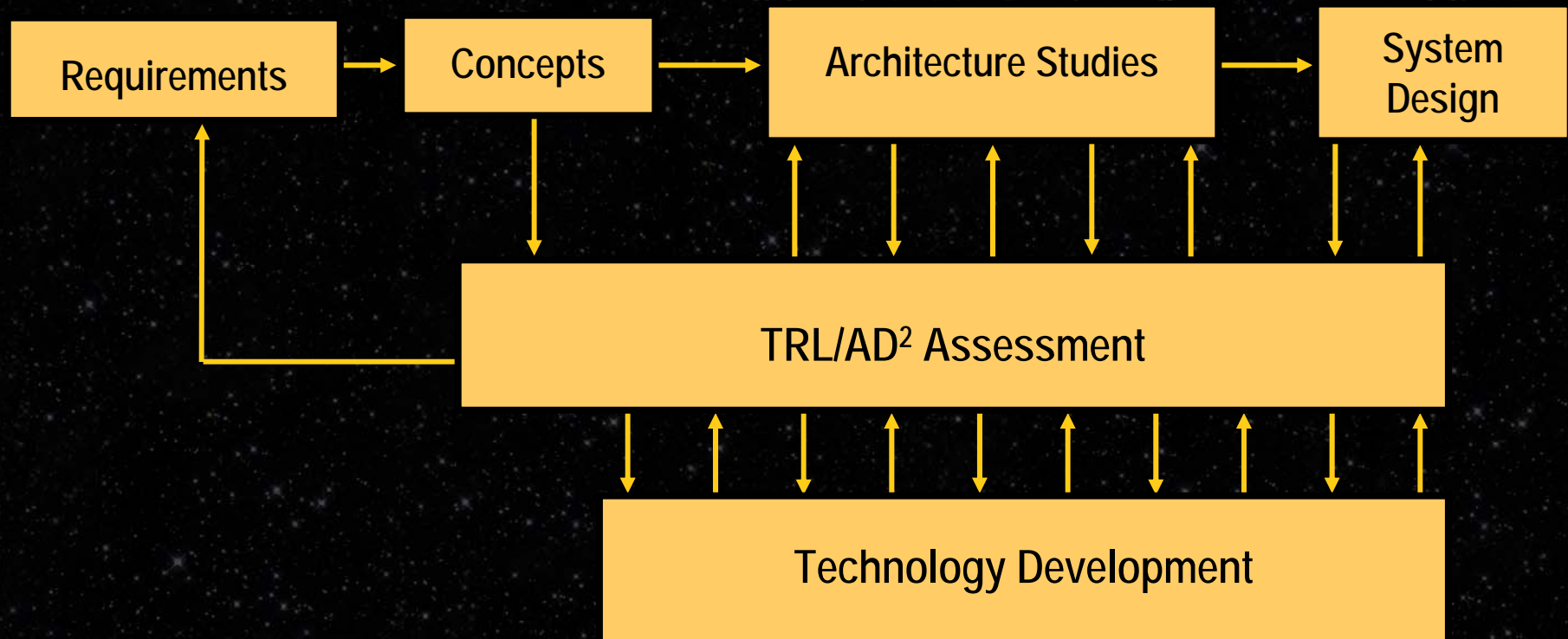
# Technology Assessment Requirements for Programs & Projects

## What is an Advancement Degree of Difficulty (AD<sup>2</sup>)?

- AD<sup>2</sup> is a method of dealing with the other aspects beyond TRL, it is the description of what is required to move a technology from one TRL to another.
- It also takes into account:
  - the organizational aspects (ability of an organization to reproduce existing technology)
  - manufacturability (MRL)
  - Integration (IRL)
  - Tools & facilities (CRL)
  - Human Readiness Levels (HRL) (skills)
  - Capability Readiness Levels (CRL) (people and tools)
  - Software Readiness Levels (SRL) (but not well)

# Technology Assessment Requirements for Programs & Projects

## Architecture Studies And the Technology Assessment Process



# Technology Assessment Requirements for Programs & Projects

## 1. Culture:

There really are four very distinct cultural differences among the community involved in any typical program.

- Scientists, who know all there is to know about science and furthermore think they know everything about engineering and technology.
- Engineers, who know all there is to know about engineering, think they know everything about technology and don't give a \*\*\*\*\* about science.

# Technology Assessment Requirements for Programs & Projects

- Technologists, who really do know all there is to know about technology, know what they need to know about science and could do engineering if they wanted to.
- Everyone else (including Program Managers)
- Now the main thing in common with the first 3 groups is that they all agree that the 4th group doesn't know anything about anything – *especially* Program Managers.

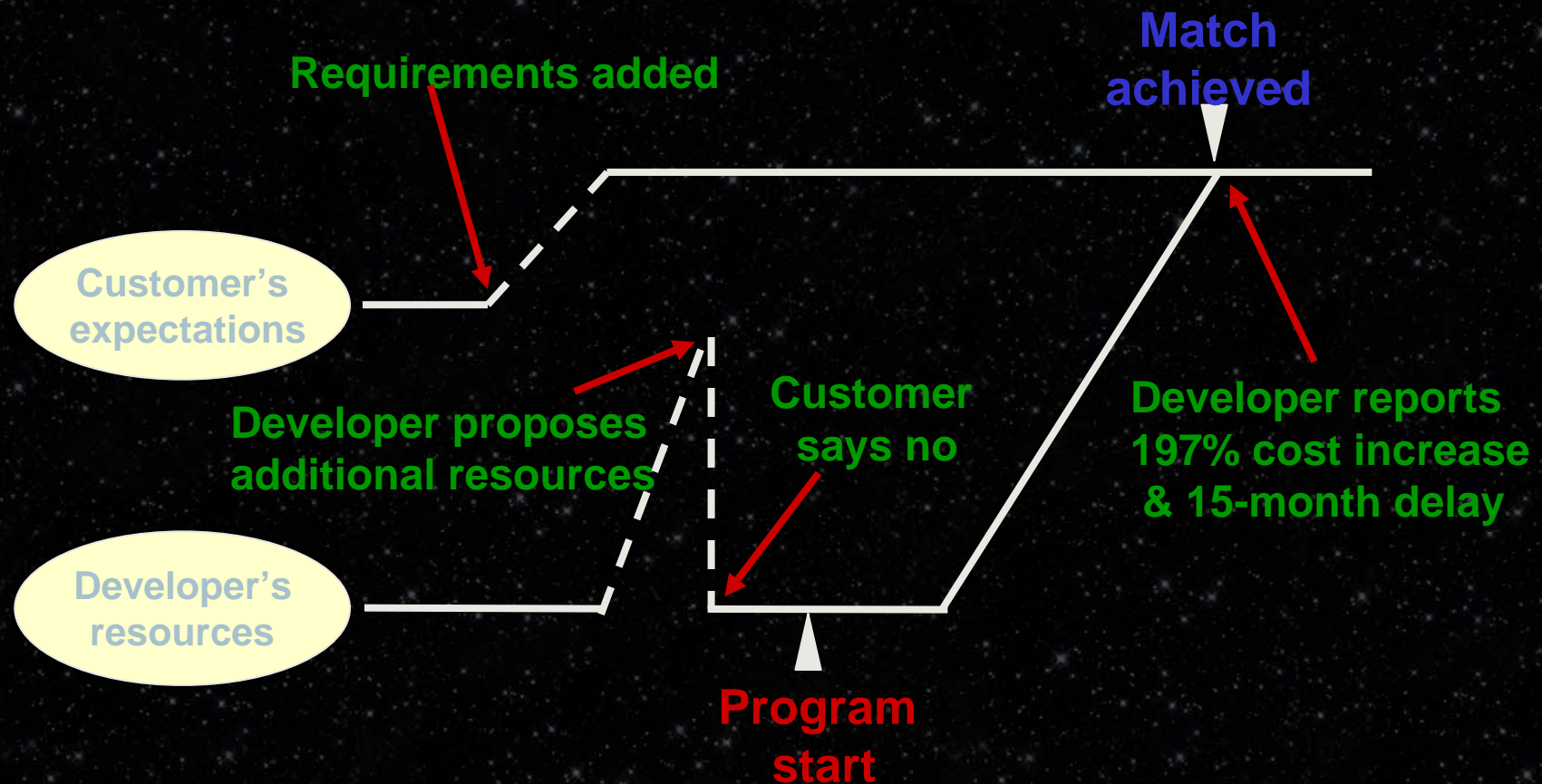
# Technology Assessment Requirements for Programs & Projects

## Why perform Technology Assessments?

- The Agency's programs and projects by their very nature require the development and infusion of technology in order to meet requirements.
- Failure to do this successfully is one of the major contributors to cost and schedule overruns.
- The following 4 slides are excerpts from a GAO presentation on their assessment of the reasons for cost and schedule overruns.

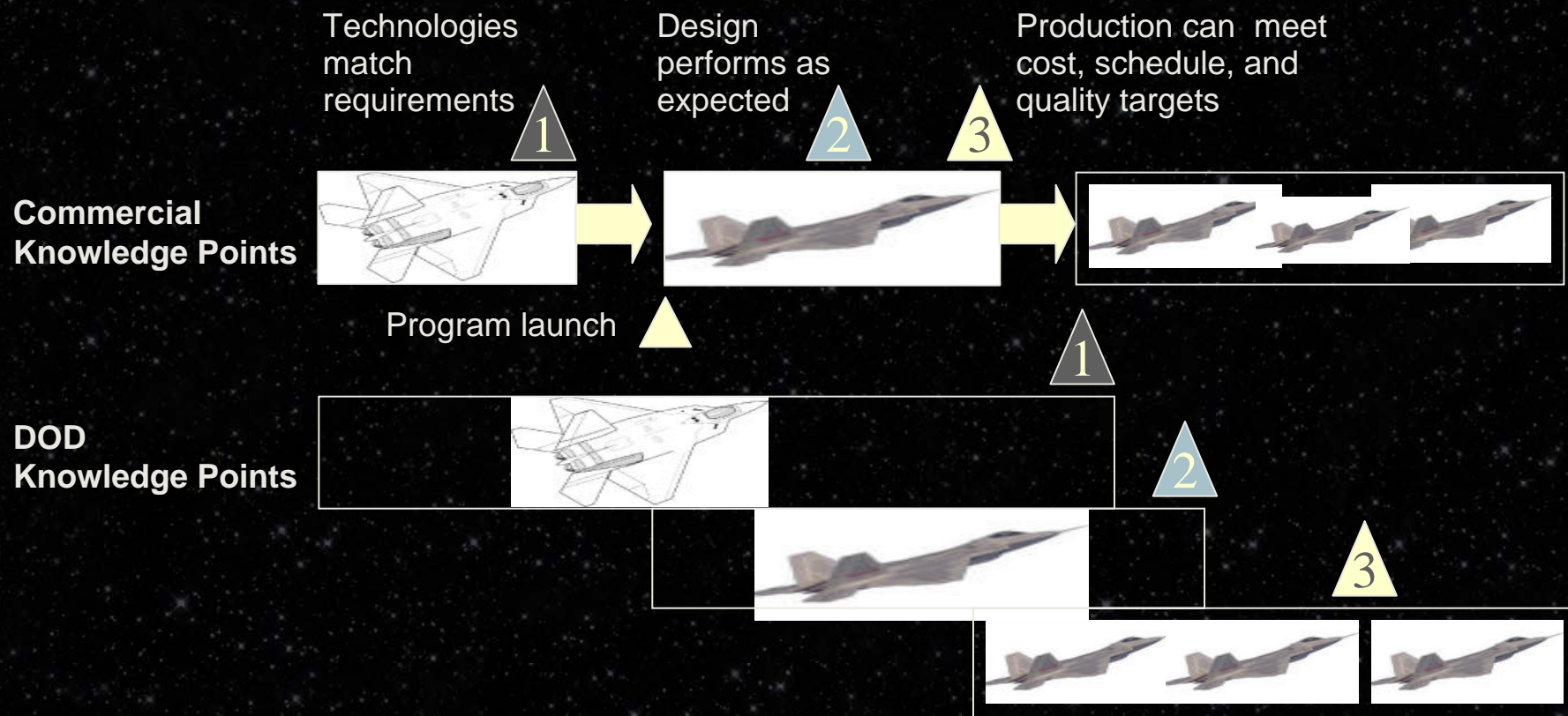
# Technology Assessment Requirements for Programs & Projects

## GAO Example of Requirements/Resource Mismatch & Resulting Overrun



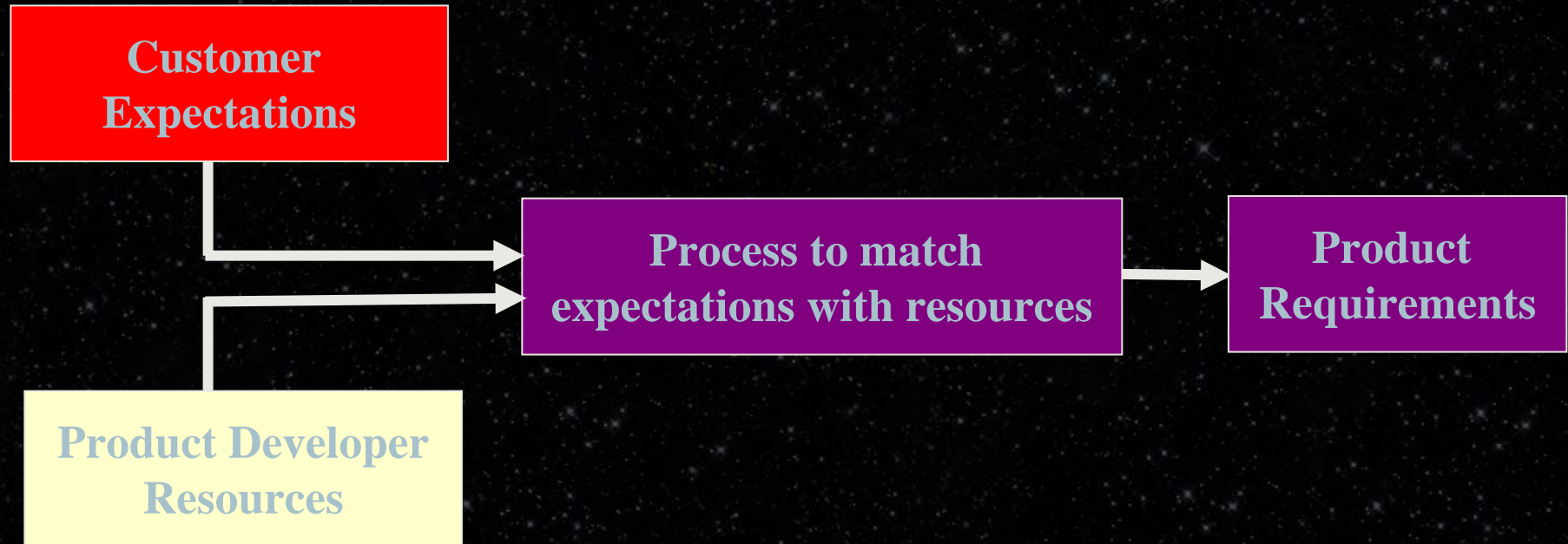
# Technology Assessment Requirements for Programs & Projects

## Knowledge Building for Development of New Products – GAO Study Results



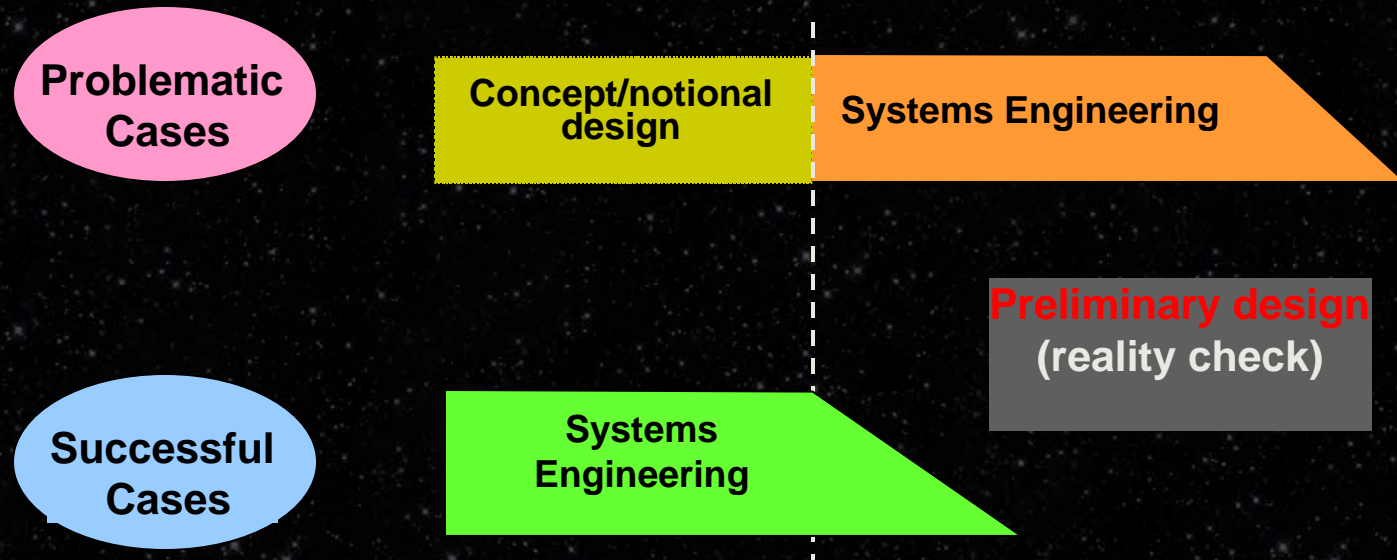
# Technology Assessment Requirements for Programs & Projects

## Reconciling Expectations, Resources, and Requirements – GAO Study Results



# Technology Assessment Requirements for Programs & Projects

## Timing of Systems Engineering – GAO Study Results



# Technology Assessment Requirements for Programs & Projects

## Program/project Risk

In a recent article in the Sloan Management review, uncertainty (risk) was broken down into 4 categories:

1. Variation
2. Foreseen uncertainty
3. Unforeseen uncertainty (unknown-unknowns)
4. Chaos

These four categories of uncertainty require different approaches from the management team if they are to be successfully resolved.

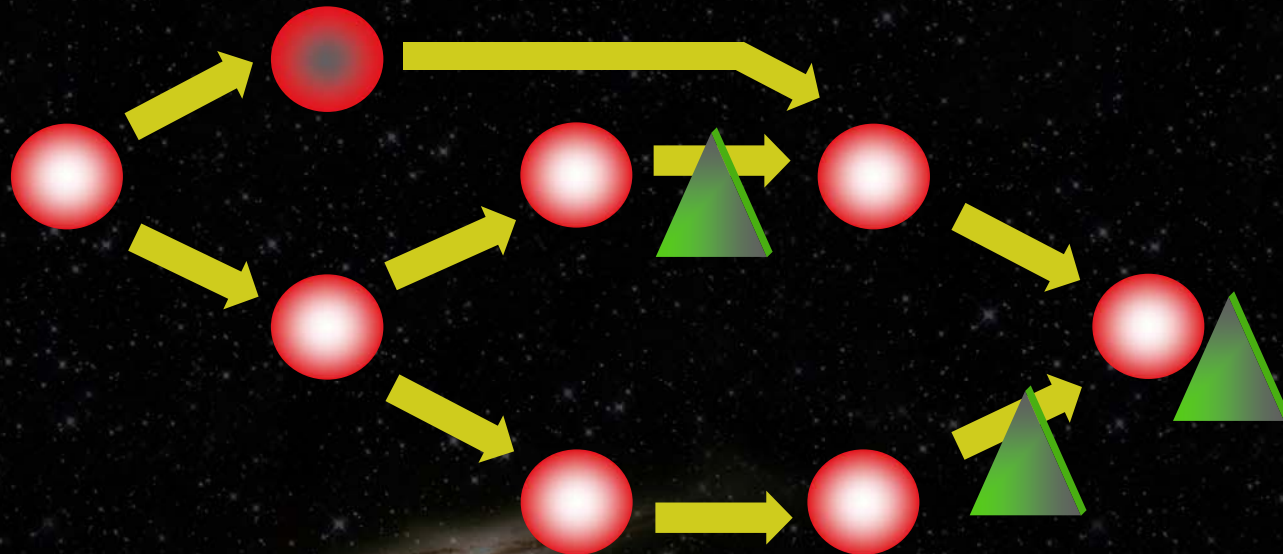
# Characterizing the Uncertainty in Projects

## Type of Uncertainty

### Variation

Cost, time and performance levels vary randomly, but in a predictable range.

- A linear flow of coordinated tasks (circles below) represents the critical path toward project completion.
- Variation in task times will cause the path to shift.
- Anticipating shifts and building in buffers (triangles) helps the team to complete project within a predictable range.



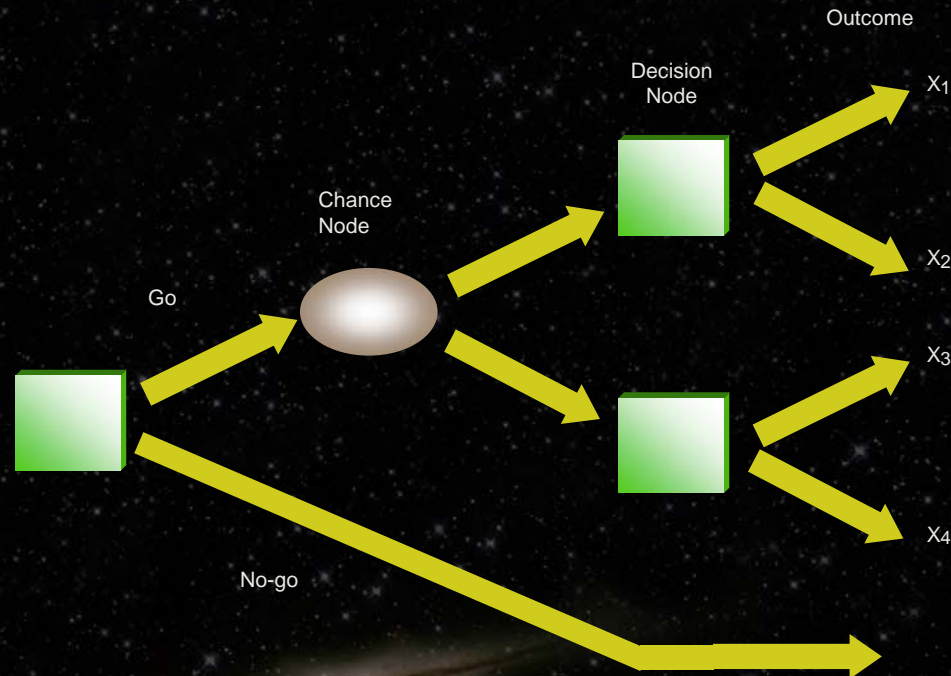
# Characterizing the Uncertainty in Projects

## Type of Uncertainty

### Foreseen Certainty

A few known factors will influence the project, but in predictable ways.

- Major project risks, or “chance nodes” (circles), can be identified.
- Contingent actions can be planned (squares), depending upon actual events and desired outcomes (Xs).



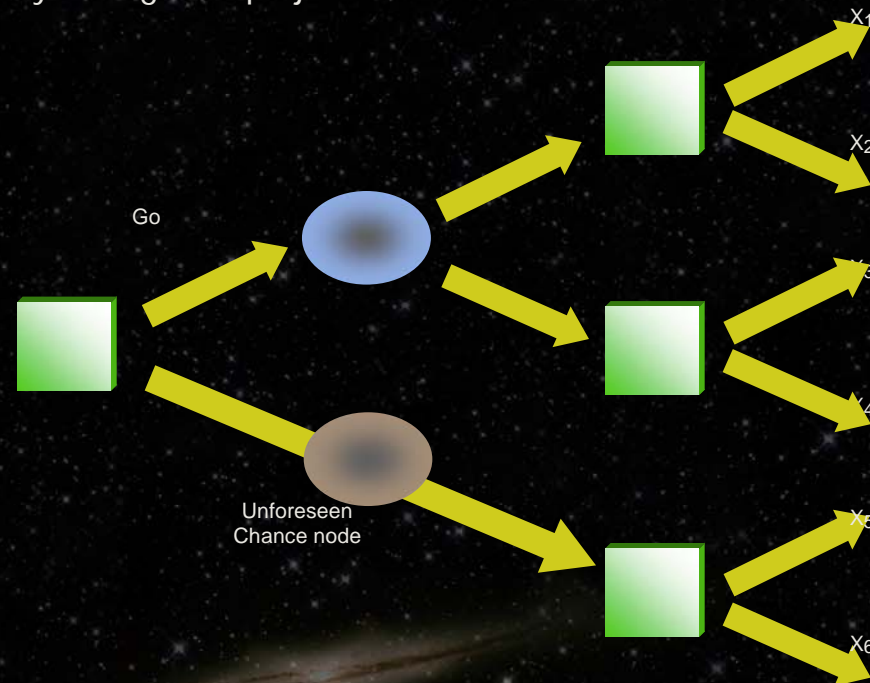
# Characterizing the Uncertainty in Projects

## Type of Uncertainty

### Unforeseen Uncertainty

One or more major influence factors cannot be predicted.

- The project team can still formulate a decision tree that appropriately represents the major risks and contingent actions
- It must recognize an unforeseen chance node when it occurs and develop new contingency plans midway through the project.



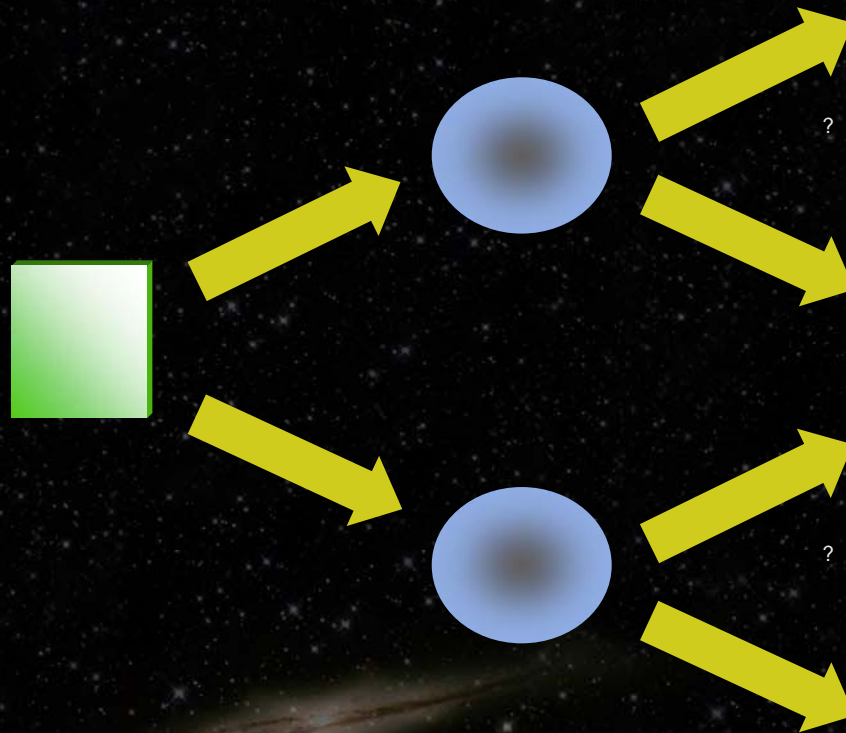
# Characterizing the Uncertainty in Projects

## Type of Uncertainty

### Chaos

Unforeseen events completely invalidate the project's target, planning and approach.

- The project team must continually redefine the project's basic premises and create new decision trees based on incremental learning.
- Medium- and long-term contingencies are not plannable.



# Technology Assessment Requirements for Programs & Projects

## Uncertainty Profile

- Creating an uncertainty profile of a program or project can provide valuable information relative to what is required to manage a program successfully.
- While there are many different elements that contribute to program/project uncertainty, a good case can be made for lack of technology maturity being the dominant component in the latter two categories:
  - Unforeseen Uncertainty
  - Chaos.

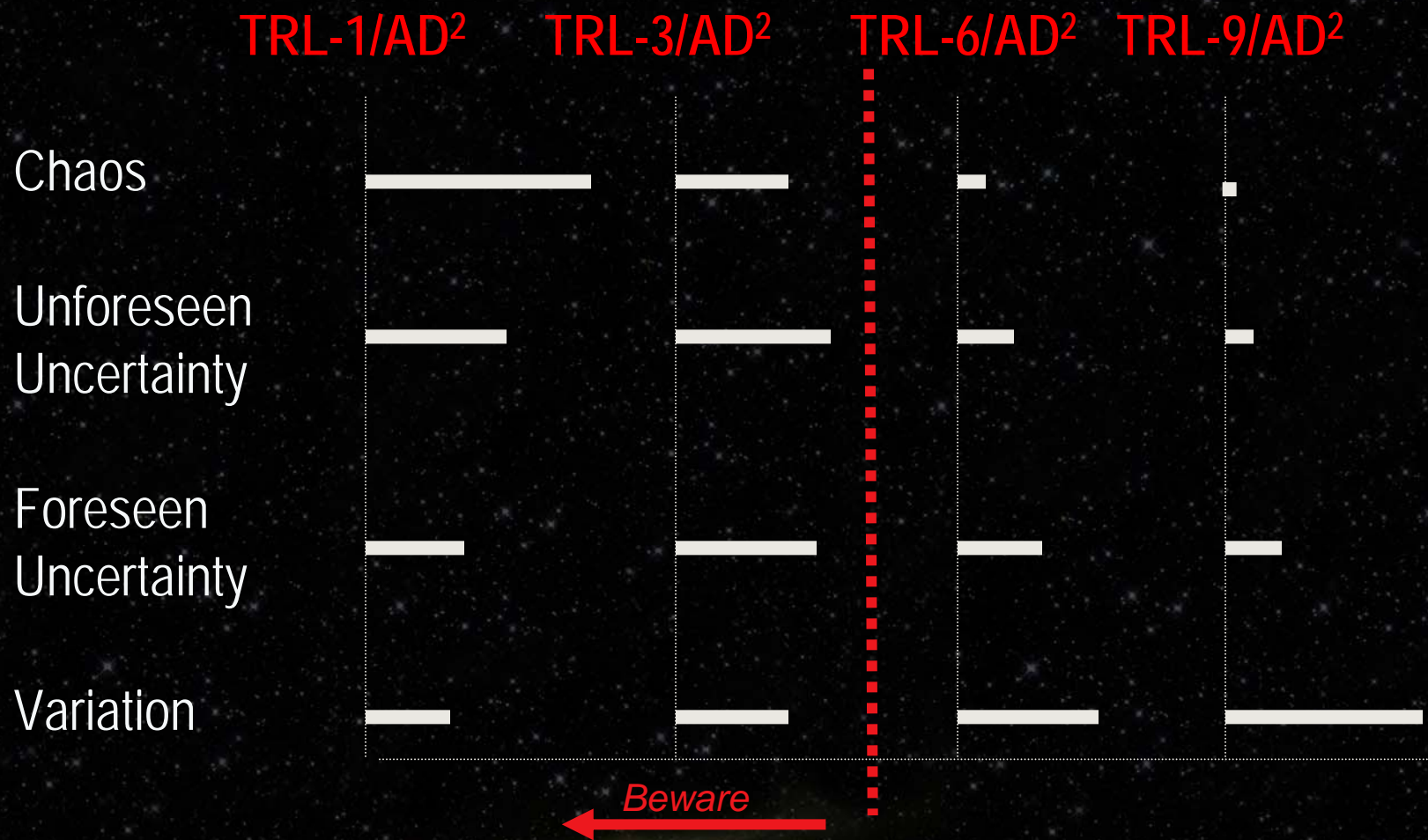
# Technology Assessment Requirements for Programs & Projects

## Uncertainty Profile

- Uncertainty profiles can be created based on Technology Readiness Levels in combination with their associated Advancement Degree of Difficulty.
- Different Flight Programs will have different uncertainty profiles depending upon the amount and maturity of the technologies that must be infused for the program to be successful and the difficulty required in advancing the technologies to the point where they can be successfully infused.

# Technology Assessment Requirements for Programs & Projects

## Uncertainty Profile



# Technology Assessment Requirements for Programs & Projects

## The Assessment Process

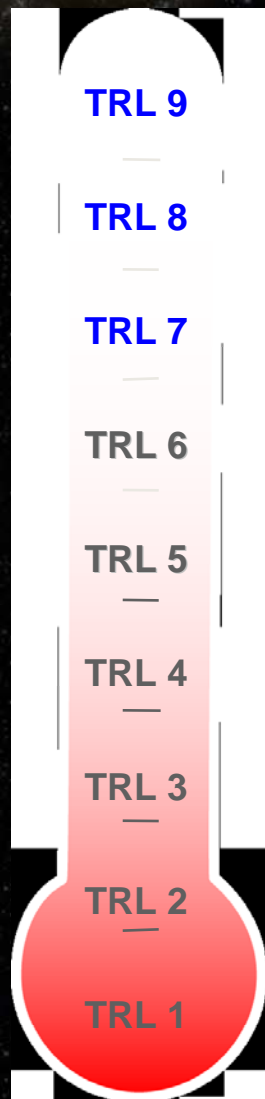
# Technology Assessment Requirements for Programs & Projects

## What is a Technology Readiness Level Assessment?

- It is the assessment of the state-of-the-art (i.e. maturity) of a given technology relative to the categories described by the Technology Readiness Levels.
- For a system, subsystem or element, the TRL for the whole is determined by the lowest TRL of its components.
- At its most basic level, the TRL is a description of what has been done at a given point in time.

**NB: Operation results are critical to determining TRLs. Tests must be done in the proper environment and the unit tested must be of an appropriate scale and fidelity.**

# Technology Assessment Requirements for Programs & Projects



Actual system “flight proven” through successful mission operations

Actual system completed and “flight qualified” through test and demonstration (Ground or Flight)

System prototype demonstration in a space environment

System/subsystem model or prototype demonstration in a relevant environment (Ground or Space)

Component and/or breadboard validation in relevant environment

Component and/or breadboard validation in laboratory environment

Analytical and experimental critical function and/or characteristic proof-of-concept

Technology concept and/or application formulated

Basic principles observed and reported

# Technology Assessment Requirements for Programs & Projects

## What is a Technology Readiness Level Assessment?

The TRL Assessment starts with a definition of the terms used in the TRL descriptions, without a common set of definitions, the assessment will be of marginal use!

# Technology Assessment Requirements for Programs & Projects

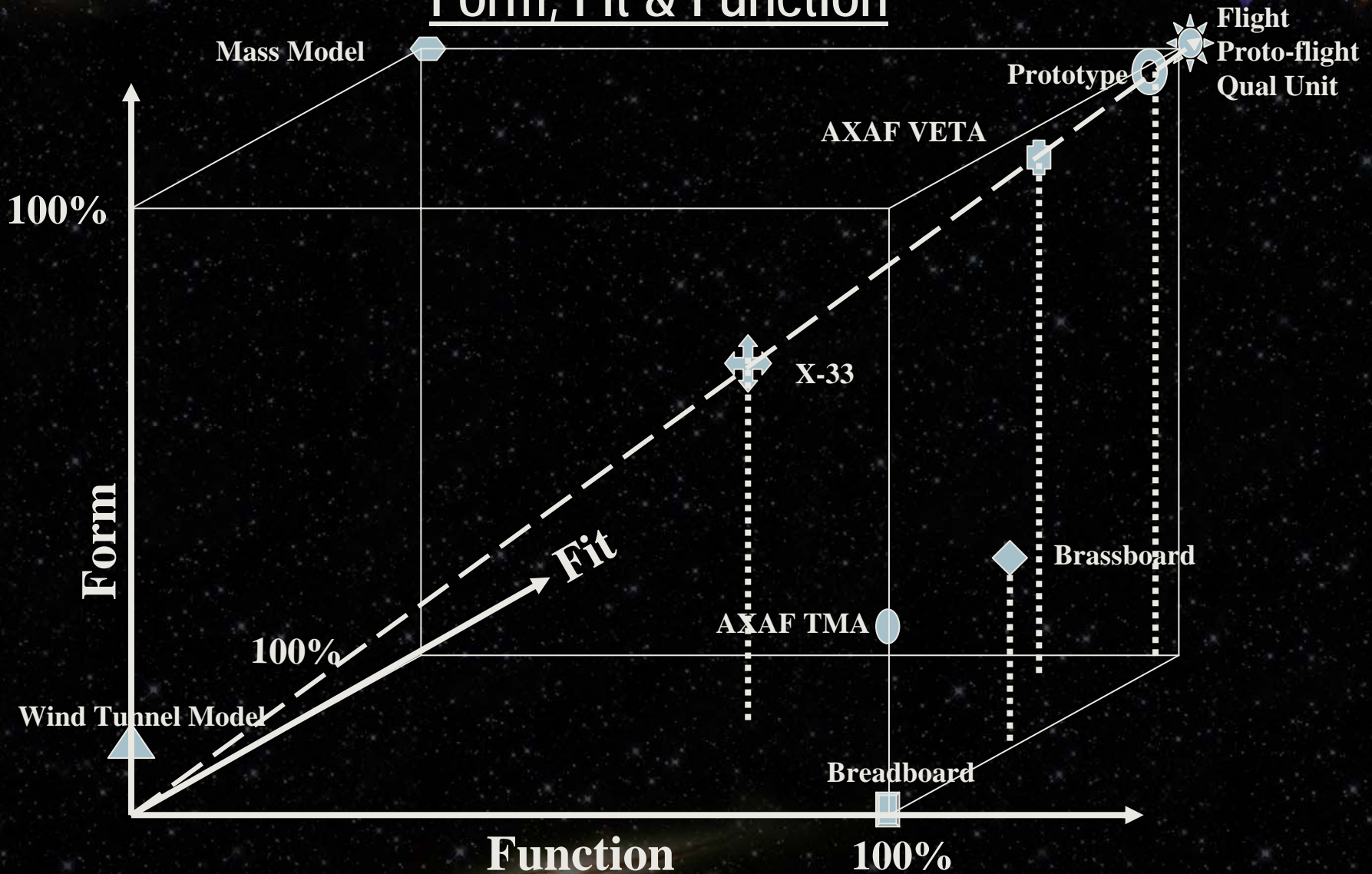
## Example of Definitions

**Proto-type Unit:** The proto-type unit demonstrates form, fit and function. It is to every possible extent identical to flight hardware, and is built to test the manufacturing and testing processes and is intended to be tested to flight qualification levels. the only difference from the flight unit is that it is realized that elements of the proto-type unit will in all probability be changed as a result of experiences encountered in the development and testing of the Proto-type unit.

**Relevant Environment:** Not all systems, subsystems and/or components need to be operated in a full space/launch environment in order to satisfactorily address performance margin requirements. Consequently, the specific environment is tailored to the performance requirements being addressed.

# Technology Assessment Requirements for Programs & Projects

## Form, Fit & Function



# Technology Assessment Requirements for Programs & Projects

Once definitions have been agreed to then a series of questions may be asked that will determine the TRL.

# Technology Assessment Requirements for Programs & Projects

## TRL Assessment

Has an identical unit been successfully operated in space or launch in an identical configuration?

YES

TRL 9

NO

Has an identical unit been flight qualified, for an identical system & environment but not yet flown in space or launched?

YES

TRL 8

NO

Has an identical unit been demonstrated in space or launch but in a different configuration, system or Environment?

YES

TRL 5?

NO

# Technology Assessment Requirements for Programs & Projects

## TRL Assessment

Has a prototype unit (or one similar enough to be considered a prototype) been demonstrated in space or launch?

YES

TRL 7

NO

Has a prototype unit (or one similar enough to be considered a prototype) been demonstrated in a relevant environment e.g. thermal vac, acoustic, dynamic loads, etc.?

YES

TRL 6

NO

***Beware - Land of the Unknown  
(There be monsters here)***

# Technology Assessment Requirements for Programs & Projects

## TRL Assessment

- Repeat the process for all subsystems, identifying the TRLs corresponding to each subsystem.
- Repeat the process for all elements of each subsystem, identifying the TRL corresponding to each element within a subsystem.
- The lowest TRL of the lowest element is the TRL of the system.

**NB: Although TRL 6 is often referred to as the “magic” level above which there is no problem, in fact the AD<sup>2</sup> assessment must be done in order to quantify the cost, schedule and risk even for those technologies above TRL 6.**

# Technology Assessment Requirements for Programs & Projects

## TRL Assessment Matrix

TRL Assessment															
<div> <div></div> <div>Red = Below TRL 3</div> </div> <div> <div></div> <div>Yellow = TRL 3, 4 &amp; 5</div> </div> <div> <div></div> <div>Green = TRL 6 and above</div> </div> <div> <div></div> <div>White = Unknown</div> </div> <div> <div>X</div> <div>Exists</div> </div>	Concept	Demonstration Units					Environment				Unit Description				Overall TRL
		Breadboard	Brassboard	Developmental Model	Prototype	Flight Qualified	Laboratory Environment	Relevant Environment	Space Environment	Space/Launch Operation	Form	Fit	Function	Appropriate Scale	
1.0 System															
1.1 Subsystem X															
1.1.1 Mechanical Components															
1.1.2 Mechanical Systems															
1.1.3 Electrical Components					X				X		X	X	X		
1.1.4 Electrical Systems															

# Technology Assessment Requirements for Programs & Projects

## What is an Advancement Degree of Difficulty (AD<sup>2</sup>)?

- Identifying the TRLs of the systems, subsystems and components is just one part of the equation – it establishes the baseline maturity.
- The more fundamental question is what is required (in terms of cost, schedule and risk) to advance the maturity to a level necessary for successful incorporation into the program.
- The AD<sup>2</sup> incorporates:
  - manufacturability (Manufacturing Readiness Levels - MRLs)
  - integration (Integration Readiness Levels - IRLs)
  - tools and capabilities (Capability Readiness Levels - CRLs)

# Technology Assessment Requirements for Programs & Projects

## AD<sup>2</sup> Assessment Process

Specifically with respect to the CRL, there is an organizational aspect of technology assessment that speaks to the capability of a given organization to reproduce a technology irrespective of its maturity level. Many programs have encountered major difficulties with “heritage” technology that either could not be reproduced.

Additionally the use of “heritage” systems and components often results in important systems engineering steps being omitted under the belief that they have already been addressed – this often leads to disastrous consequences.

# Technology Assessment Requirements for Programs & Projects

## AD<sup>2</sup> Assessment Process

*Overall, AD<sup>2</sup> assessment is one of the most challenging aspects of technology assessment. – the cost, schedule and risk associated with advancing maturity levels varies greatly with the technology.*

Appropriately assessing AD<sup>2</sup> requires the art of “prediction,” which, if it is to be accurate must rely on:

- Expert personnel
- Detailed examination of required activity.
- Review by independent advisory panel

# Technology Assessment Requirements for Programs & Projects

## AD<sup>2</sup> Assessment

Having acquired the appropriate expertise, determination of the AD<sup>2</sup> is primarily a matter of:

- Addressing the appropriate questions regarding the development process
- Identifying the quantitative steps in the developments that must be undertaken (breadboards, developmental models, prototypes, etc.)
- Identifying what tests must be undertaken to certify the advancement
- Making informed assessments of the degree of difficulty in pursuing the development/testing/evaluation.

# Technology Assessment Requirements for Programs & Projects

## AD<sup>2</sup> Assessment – detailed examination of required activity

### Design/Analysis:

Do you have the necessary tools for design and analysis at the level of accuracy required? If not what needs to be done, how long will it take and how difficult will it be to accomplish it?

- Data bases
- Design methods
- Analytical tools
- Models

# Technology Assessment Requirements for Programs & Projects

## AD<sup>2</sup> Assessment -- detailed examination of required activity

### Manufacturing:

Do you have the necessary tools/processes for manufacturing at the level of accuracy required? If not what needs to be done, how long will it take and how difficult will it be to accomplish it?

- Materials
- Metrology Process development
- Tooling
- Developmental units required

# Technology Assessment Requirements for Programs & Projects

## AD<sup>2</sup> Assessment – detailed examination of required activity

### Test & Evaluation:

Do you have the necessary equipment/processes/facilities for test and evaluation at the level of accuracy required? If not what needs to be done, how long will it take and how difficult will it be to accomplish it?

- Environmental Facilities
- Analysis Software
- Test units needed (breadboards, prototypes etc.)
- Test Hardware
- Special requirements

# Technology Assessment Requirements for Programs & Projects

## AD<sup>2</sup> Assessment – detailed examination of required activity

### Operability:

Throughout the development of the design, manufacturing and testing processes, operability must be taken into account.

- Ease of manufacture
- Reliability
- Life cycle costs
- Operability
- Verifiability
- Sustainability
- Reproducibility
- Testability

# Technology Assessment Requirements for Programs & Projects

## AD<sup>2</sup> Assessment Matrix

The answers to the questions can again be formulated into a matrix that indicates the level of risk associated with each area and provides the basis for subsequent cost and schedule estimates.

Not applicable	Design & Analysis				Manufacturing								Operability						Test & Evaluation						Demonstration Units					Overall Qualitative Assessment			
Red = Major Concern	Databases	Design Methods	Analytical Tools	Models	Components	Materials	Facilities	Machines	Tooling	Metrology	Mfg. Software	Mfg. Processes	Assembly & Alignment	Life Cycle Costs	Reproducibility	Manufacturability	Process Variability	Verifiability	Testability	Reliability	Integration Issues	Special Facilities	Environmental Facilities	Special Software	Special Test Equipment	Special Support Equipment	Breadboard	Brassboard	Scale Model		Engineering Unit	Prototype	Overall Numerical Score
Yellow = Moderate Concern																																	
Green = OK																																	
White = Under Evaluation																																	
Existing = 1.0																																	
Moderate Risk = 5.0																																	
High Risk = 8.0																																	
Major Breakthrough = 10.0																																	
1.0 System																																	
1.1 Subsystem																																	
1.1.1 Components																																	
1.1.2																																	
1.1.3																																	
1.1.4																																	
1.1.5																																	
1.1.6																																	
1.1.7																																	
1.1.8																																	
1.1.9																																	
1.1.10																																	
1.1.11																																	
1.1.12																																	
1.2 Subsystem																																	
1.2.1 Components																																	

# Technology Assessment Requirements for Programs & Projects

## Key Decision Points

The information contained in the TRL matrix and the corresponding AD<sup>2</sup> matrix provides the information required for key decision points (KDPS)

- Identifies Critical Technologies
- Provides for Information for Risk Mitigation Plan Preparation
  - Breadboards and Developmental Models Required
  - Tests Required
  - Alternate Approaches
  - Fall Back Positions and Corresponding Performance Reductions
- Overall Risk associated with technology maturity at each phase.

# Technology Assessment Requirements for Programs & Projects

## Cost and Schedule

The AD<sup>2</sup> assessment provides considerable detail for an accurate determination of program cost and schedule.

- The identification of data bases, tools, processes, facilities tests, scale model development and integration issues in particular will assist in developing realistic cost plans.
- The identification of requirements for engineering model development and subsequent tests will be of particular benefit in outlining realistic schedules.

# Technology Assessment Requirements for Programs & Projects

## Program/Project/Activity Technology Assessment Process Summary

- Clearly define all terminology used in the Technology Readiness Level (TRL) descriptions to be used throughout the life of the program/project/activity.
- Provide a formal assessment of the TRL for each system, subsystem and component as described by the program/project WBS. (The “weakest link” concept will be used in determining system and subsystem TRLs wherein the TRL of the system is determined by the subsystem having the lowest TRL in the system which in turn is determined by the component having the lowest TRL in the subsystem.

# Technology Assessment Requirements for Programs & Projects

## Program/Project/Activity Technology Assessment Requirements

- On the basis of the assessment prepare a Critical Technology List, i.e., a list of those technologies that are absolutely essential in meeting requirements and that have substantial risk, cost, and/or schedule involved in the development
- Prepare a risk mitigation plan (Advancement Degree of Difficulty (AD2) for each critical technology that addresses the cost, schedule and risk associated with advancing each element to the point necessary to meet requirements in a timely manner. Identify alternative paths, decision gates, off-ramps, fallback positions, and quantifiable milestones with appropriate schedules (Technical Performance Metrics (TPM's) that measure progress towards requirements and are verified by test.

# Technology Assessment Requirements for Programs & Projects

## Program/Project/Activity Technology Assessment Requirements

- Progress on risk mitigation will be tracked at periodic reviews until CDR when all appropriate risk is deemed to have been eliminated or reduced to acceptable levels.

# Technology Assessment Requirements for Programs & Projects

## Summary

Successful development and incorporation of technology into programs is a hard job! But – it is not magic, it simply requires up front application of systems engineering.

It takes time and money and effort, but in the end, it must be done if the program/project is to succeed.